Search for Dark Matter annihilations in the Sun using the completed IceCube neutrino telescope.

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for the IceCube collaboration

UNIVERSITÉ DE GENÈVE

ICECUBE

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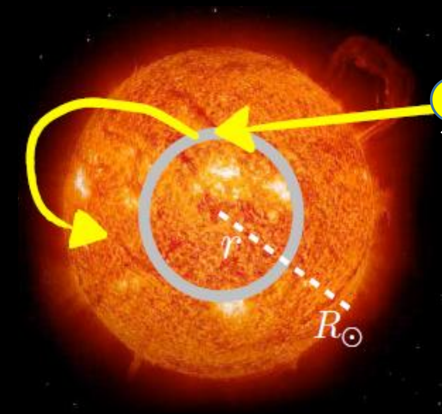
WIMP Capture and Annihilation in the Sun



$$\Gamma_{\rm capt} = \frac{\rho_{\rm DM}}{M_{\rm DM}} \sum_i \sigma_i \int_0^{R_\odot} dr\ 4\pi r^2\, n_i(r) \int_0^{\infty} dv\ 4\pi v^2 f_\odot(v) \frac{v^2 + v_{\odot \rm esc}^2}{v} \wp_i(v, v_{\odot \rm esc})$$

DM number density

Scattering Cross Section
$\sigma_{SD} \propto J(J+1)$
$\sigma_{SI} \propto A^2$

Number density of element i -> Solar Model

velocity distribution (in solar frame, without Sun's gravity)

effect of solar gravity

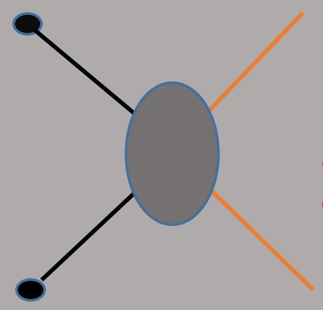
Spin Dependent scattering
- Only the hydrogen in the Sun contributes significantly.
- Lower event rates in direct detection experiments
- More interesting for IceCube

Spin Independent scattering
- Heavier nuclei contribute more due to $\propto A^2$ enhancement.
- Better sensitivity using direct detection experiments such as LUX, XENON etc

Capture

Equilibrium → $\Gamma_A^{equi} = \frac{1}{2} C_c$

Annihilation



$b, W^+, \tau^+ \ldots$

Primary annihilation channels

$\bar{b}, W^-, \tau^- \ldots$

Decay

Dense Medium

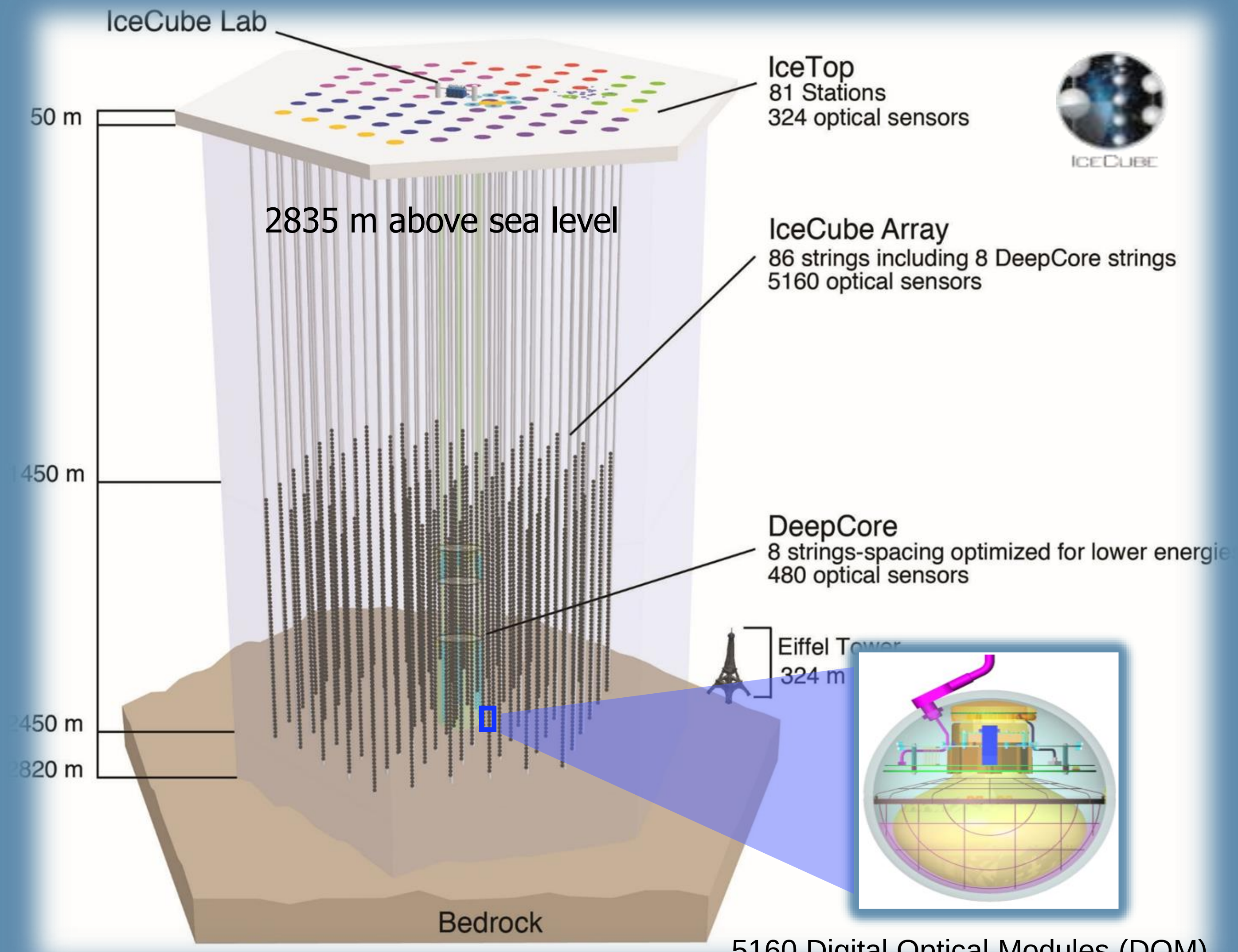
$\ldots\nu$

$\ldots\bar{\nu}$

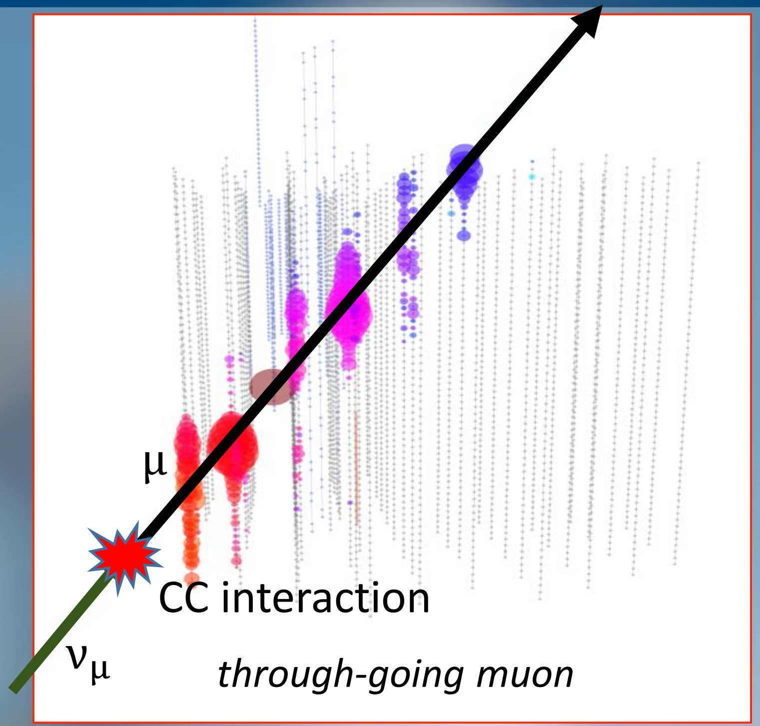
At Earth :
Enhanced neutrino flux from the direction of the Sun!

All calculations performed with DarkSusy/WimpSim

IceCube : Detector and Event Signatures



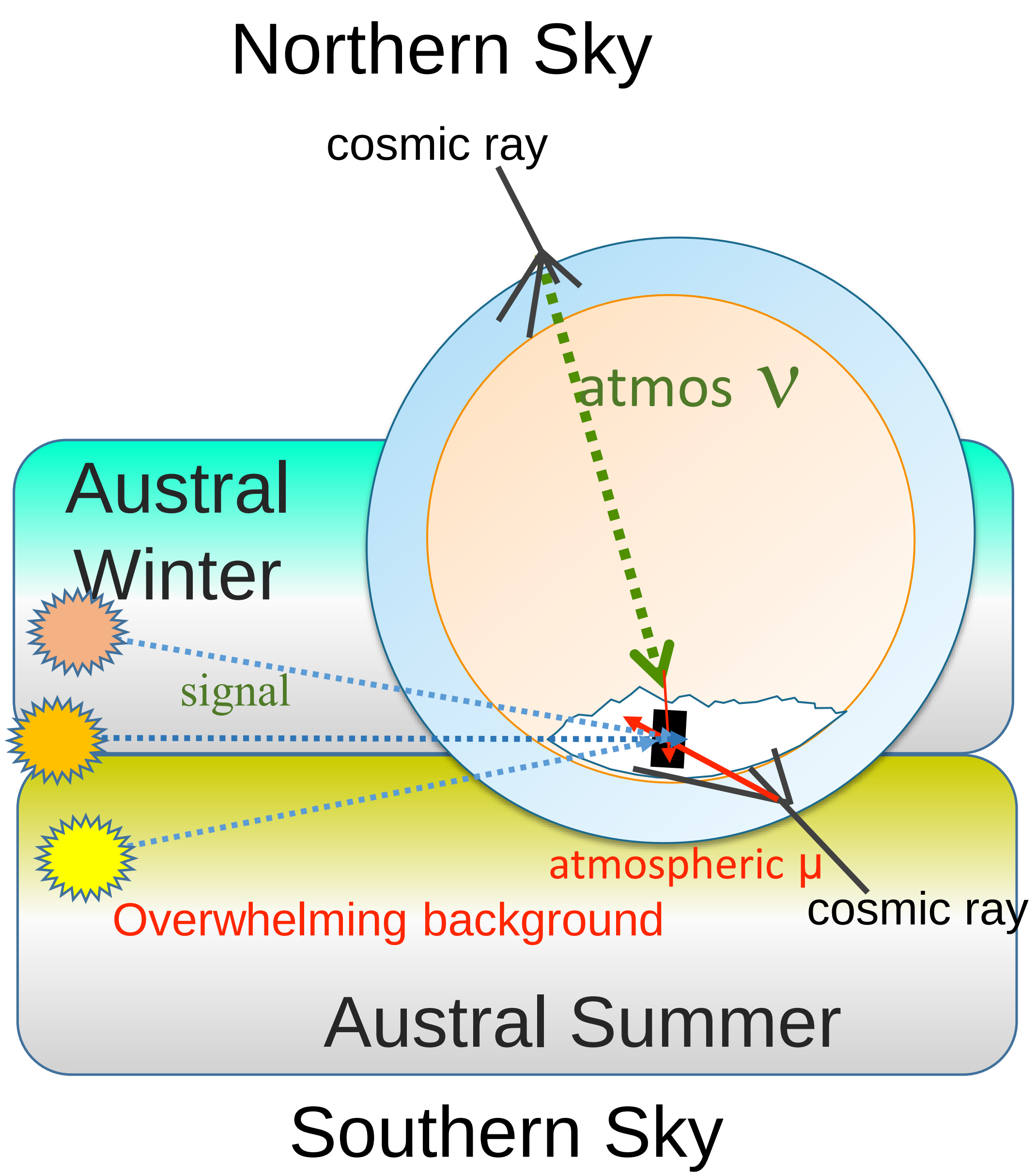
5160 Digital Optical Modules (DOM)



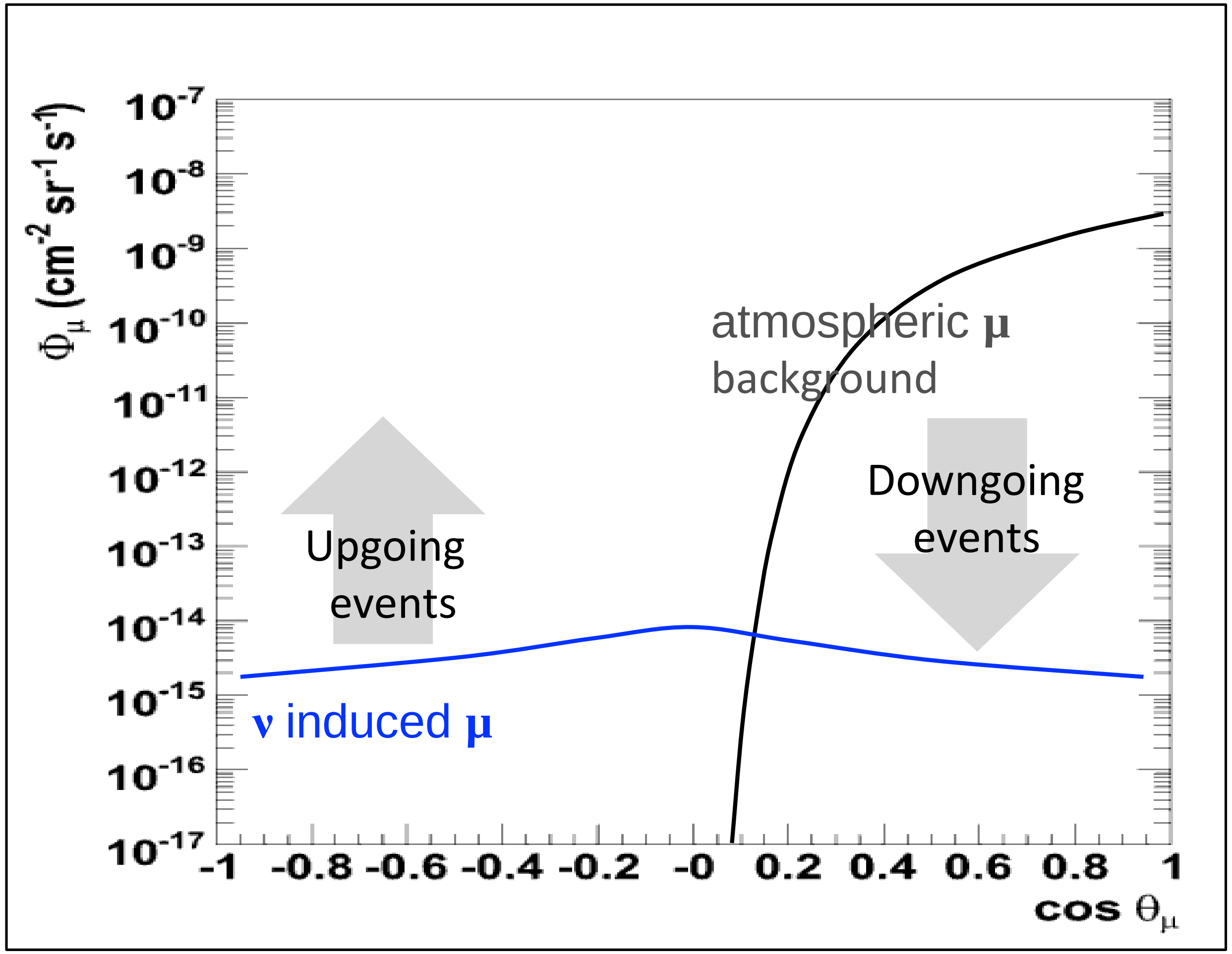
- Good angular resolution: **Neutrino Astronomy**
- Vertex can be outside the detector: **Increased effective volume!**

Other signatures such as cascades from ν_e, ν_τ and all-flavor neutral current interactions are not used in this analysis.

IceCube and the Sun



10^6 lower background during the Austral Winter

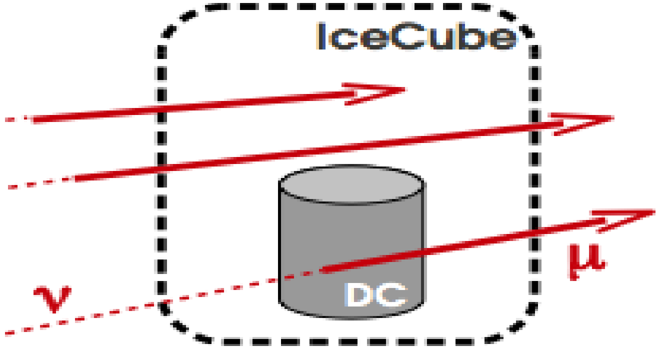


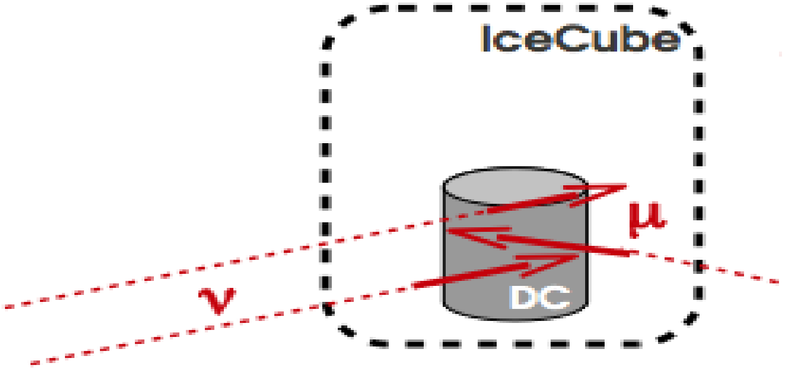
Event Selections

High Energy ①
Large Effective Volume
Excellent Angular Resolution

Low Energy ②
Better Energy Resolution

Winter



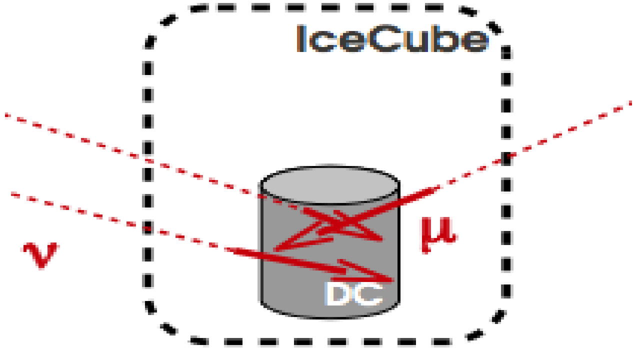


All three samples are non overlapping and hence combined in likelihood.

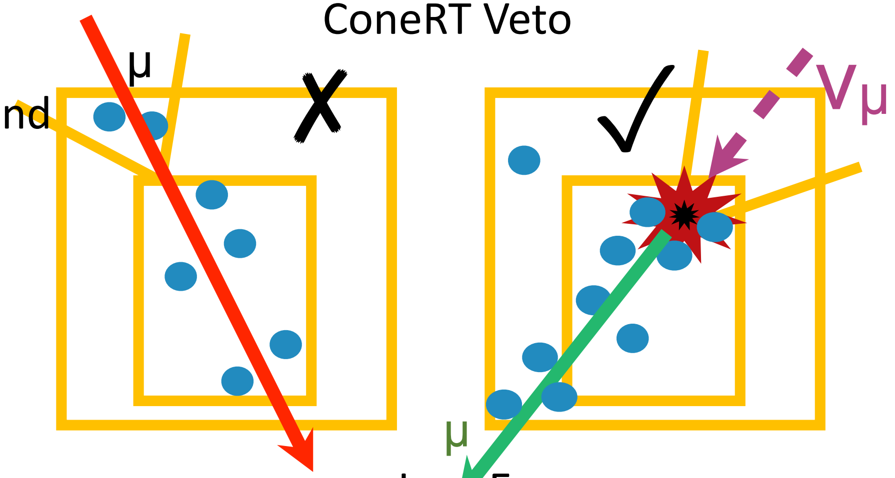
① Optimized for high energy (>100 GeV) Signals
② and ③ Optimized for low energy (<100 GeV) Signals

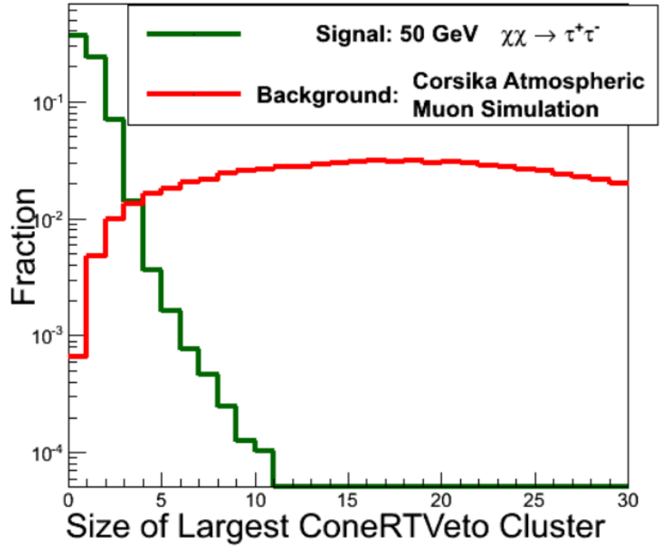
Low Energy ③
Veto to remove downgoing background

Summer

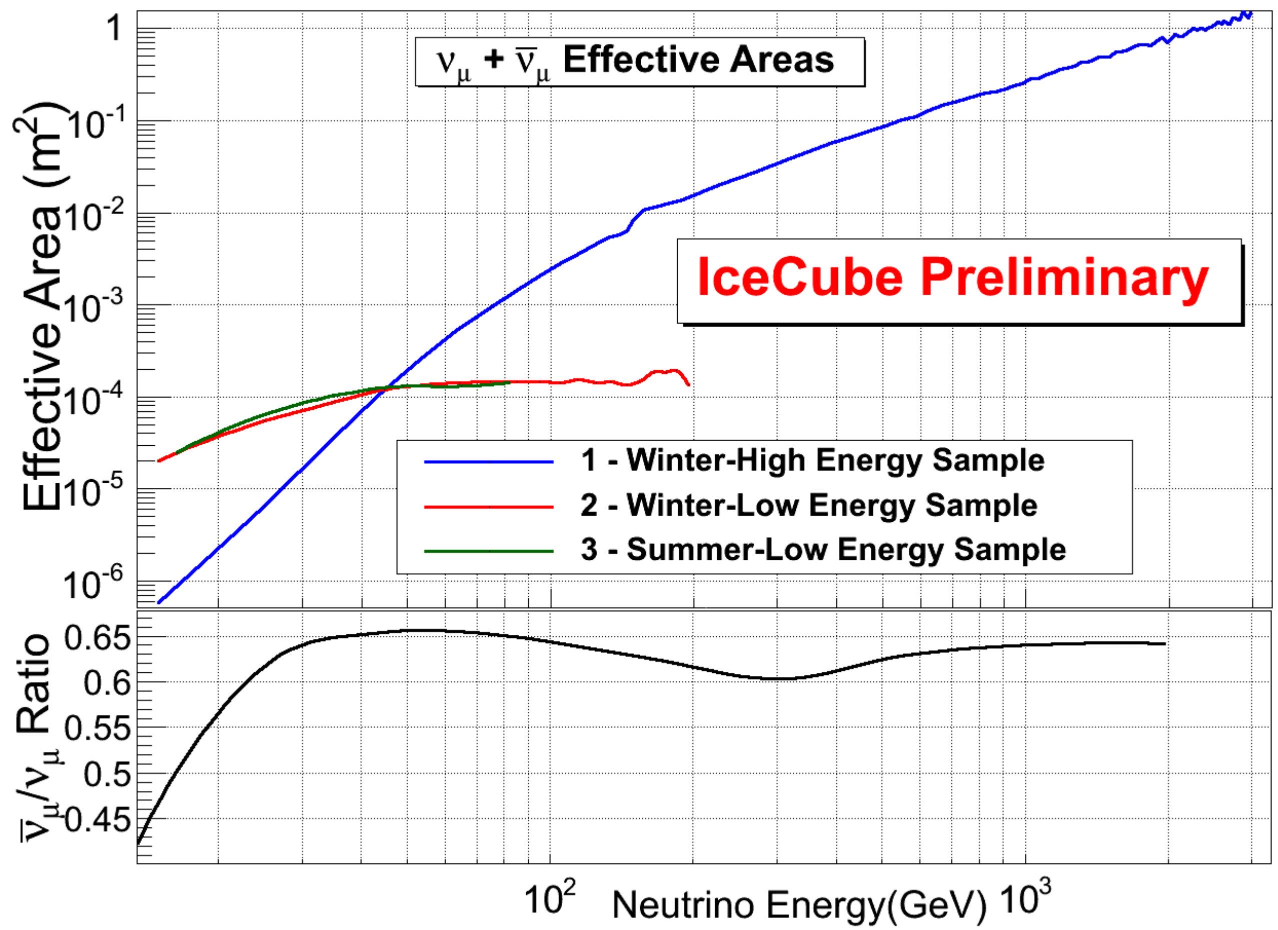


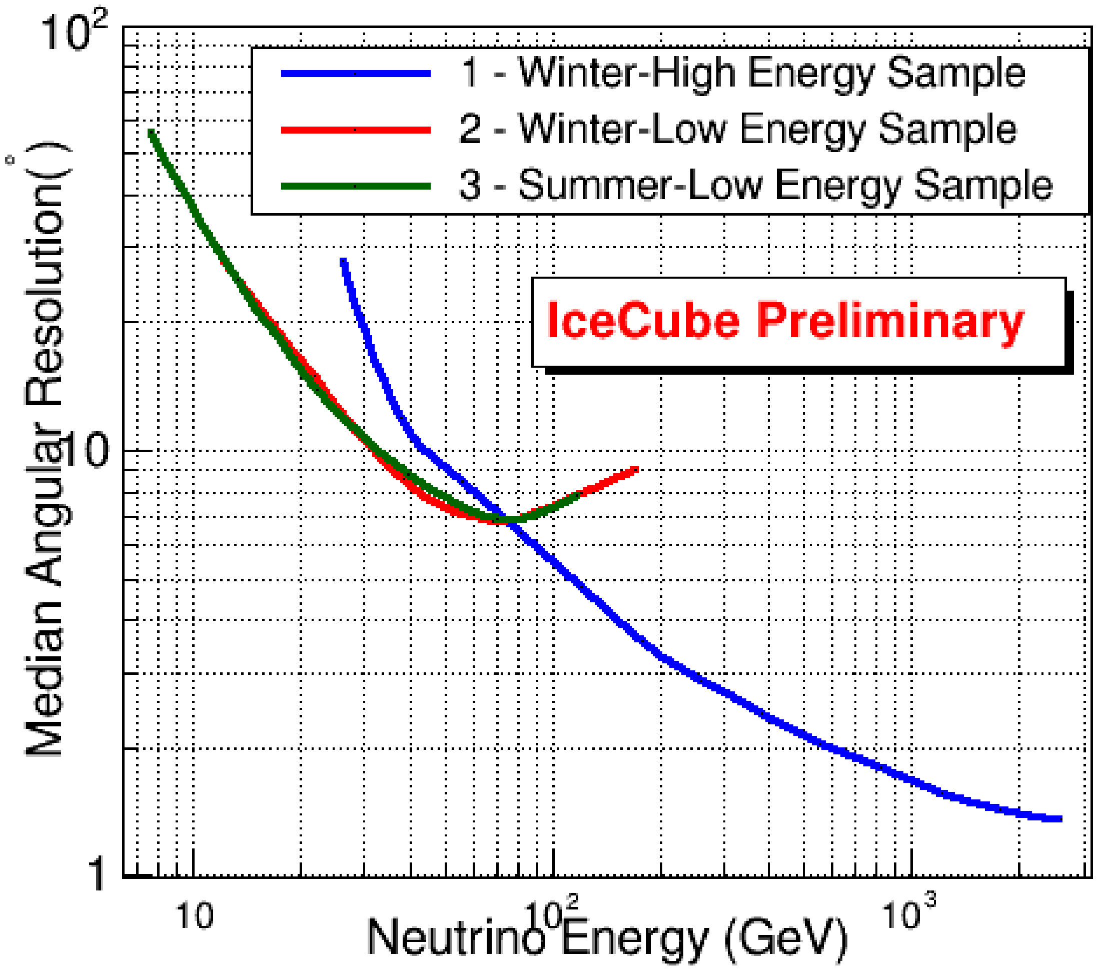
ConeRT Veto





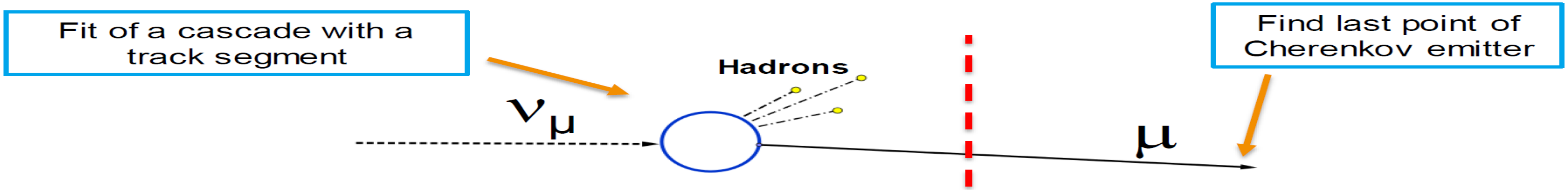
Event Selection Performance





Energy Reconstruction

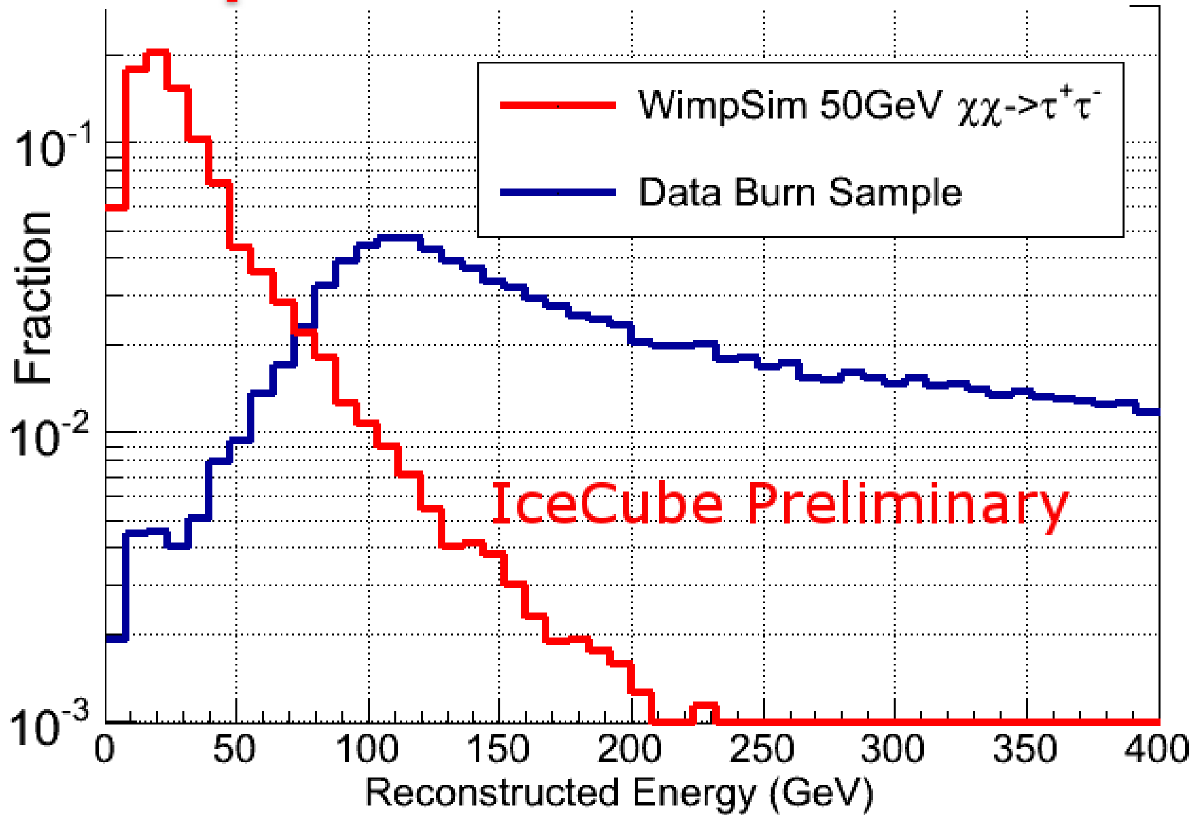
$$E_{\rm reco} = E_{\mu}(R_{\mu}) + E_{\rm vertex}(E_{\rm had}, \vec{x}_{\rm vertex})$$



A full neutrino energy estimator for contained tracks

Enhances signal to background discrimination, and hence sensitivity for the low energy samples

2 and 3

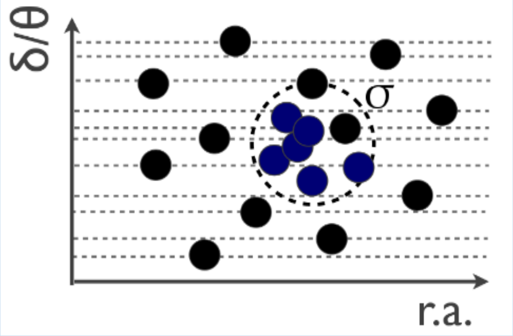


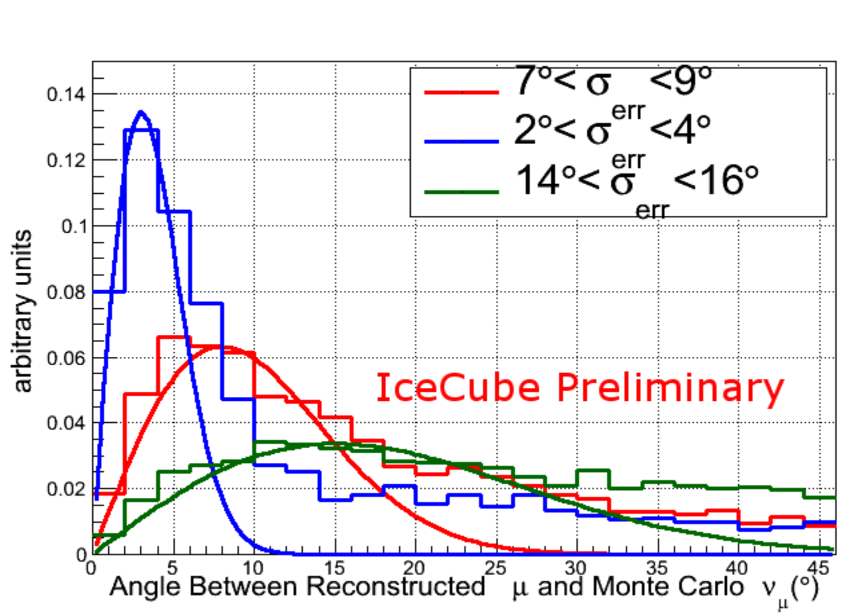
Analysis Method

Signal

$$S_i(m_\chi, c) = Kent(\alpha_{sun}, \delta_{sun}, \alpha_i, \delta_i, \sigma_i) . P(E_i | m_\chi, c)$$

Spatially clustered around the Sun





Background

$$B_i = B(\theta_i) . P_{atm}(E_i)$$

Background estimated from Scrambled data – independent of Monte Carlo

Significance is estimated from repeated trials on scrambled data

Likelihood

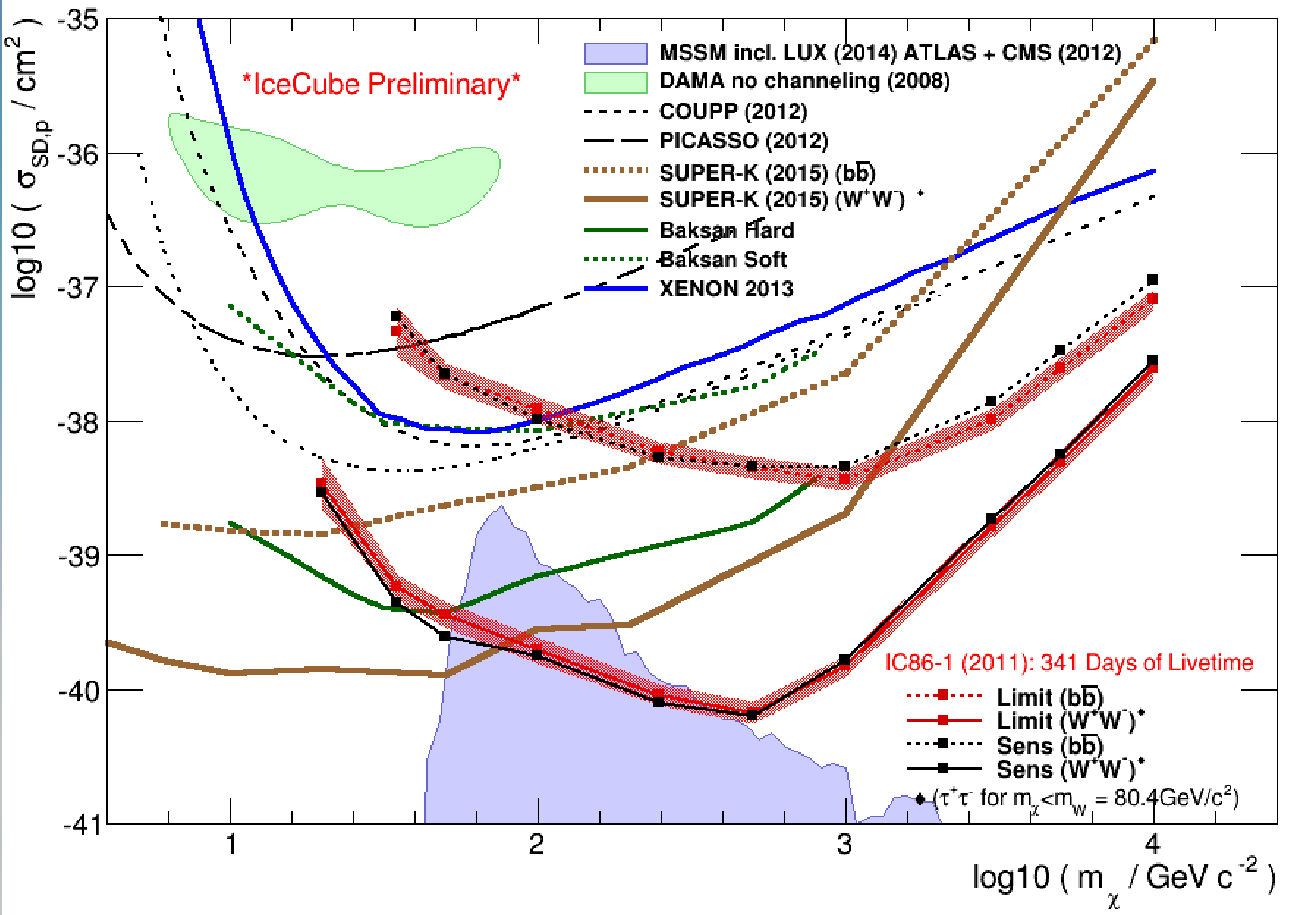
$$\mathcal{L}(n_s) = \prod_{i=1}^{N} \left(\frac{n_s}{N} S_i(m_\chi, c) + (1 - \frac{n_s}{N}) B_i\right)$$

Test Statistic

$$TS = log\left[\frac{\mathcal{L}(\hat{n}_s)}{\mathcal{L}(n_s = 0)}\right]$$

Confidence intervals on n_s are constructed using the method of Feldman and Cousins.

Results



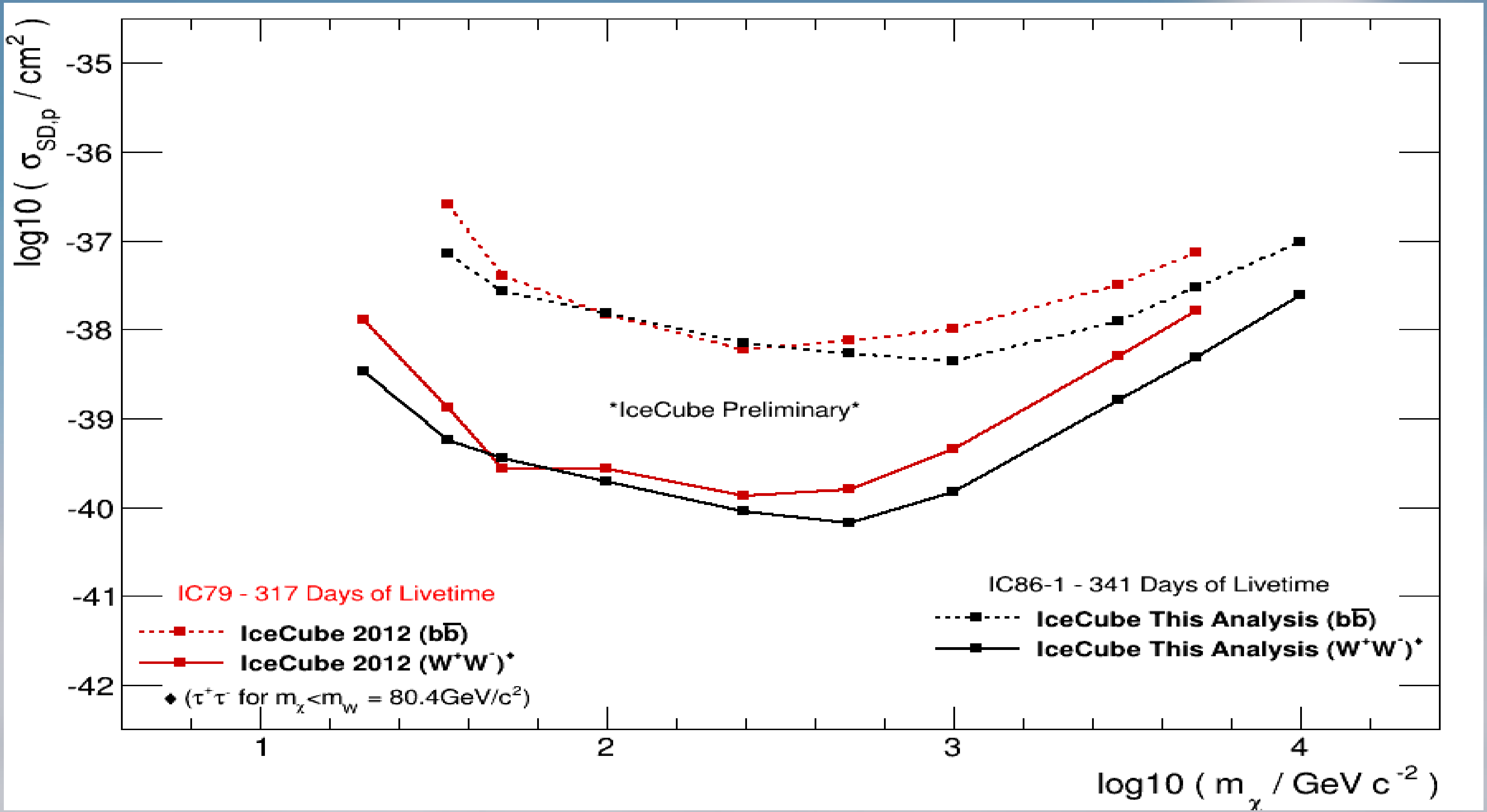
Assume equilibrium between capture and annihilation in the sun -> Set limit on WIMP-Nucleon scattering cross section

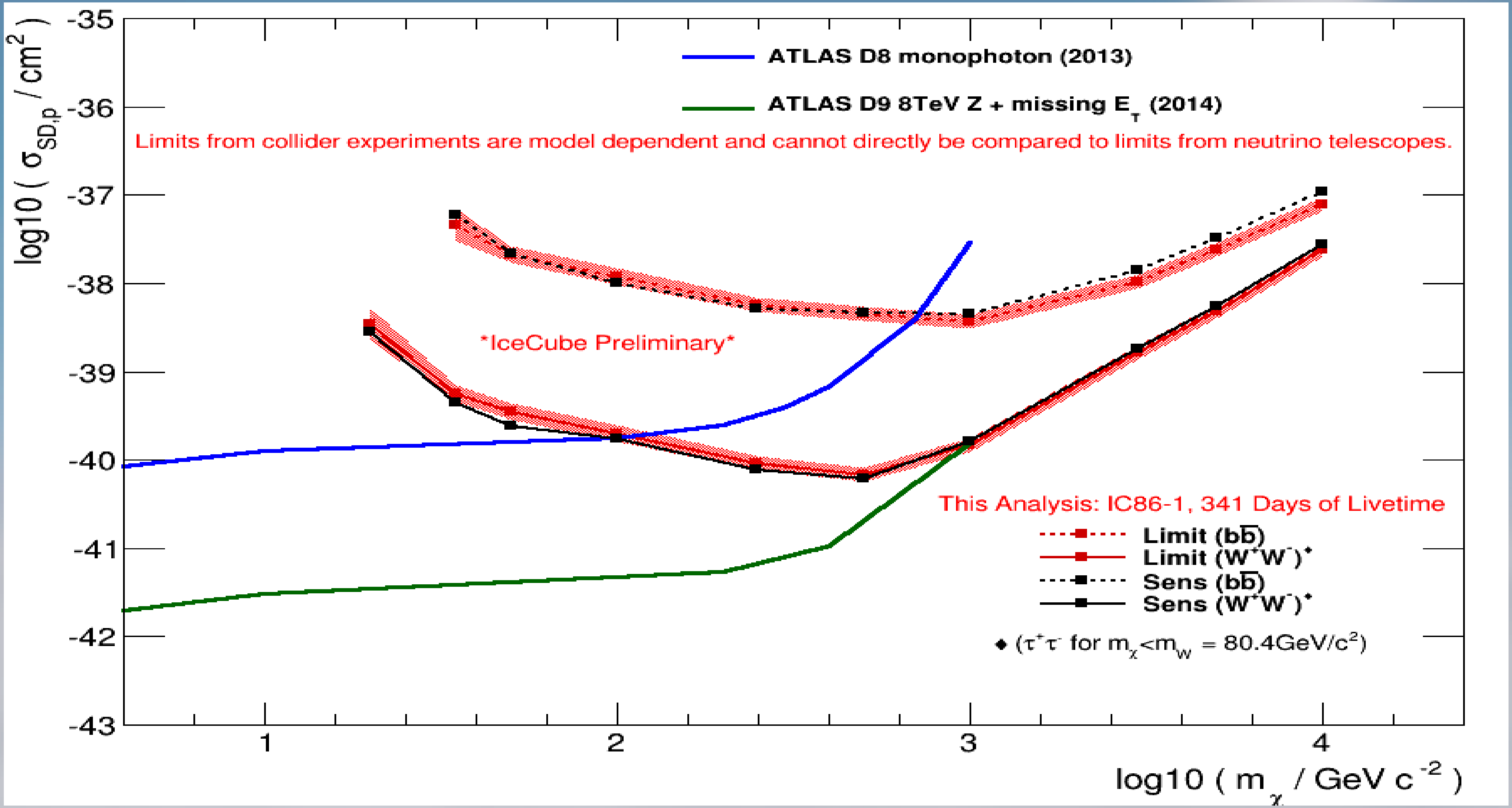
Comparable to direct detection experiments.

For a different analysis of the same data that has produced consistent results, see:
IceCube Coll., PoS (ICRC2015) 1099 these proceeding
Poster 2 - DM and NU session, NU-EX Track, Board #269

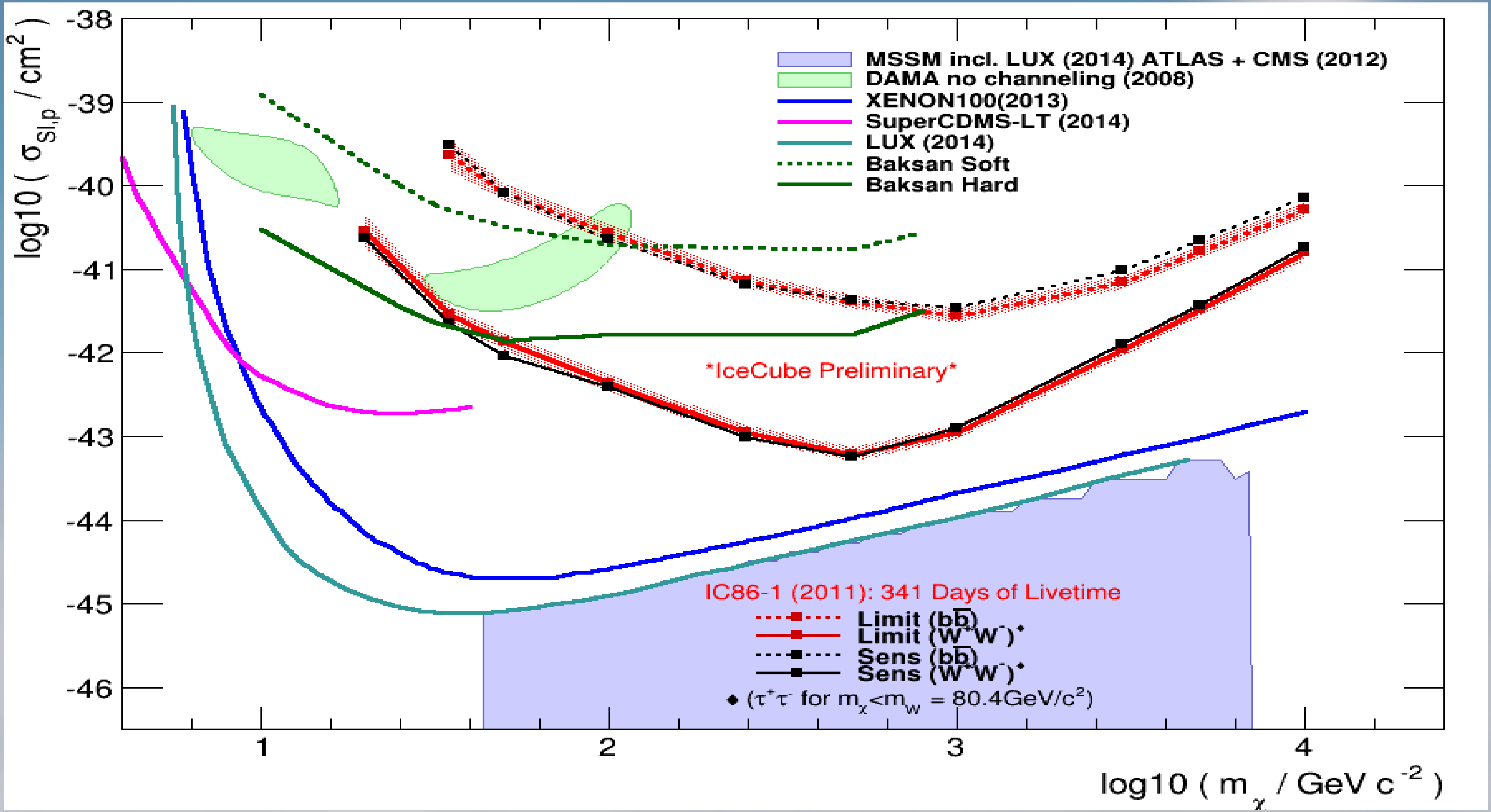
Backup Slides

Comparison with previous IceCube Analysis




ATLAS D8 monophoton (2013)
ATLAS D9 8TeV Z + missing E_T (2014)
Limits from collider experiments are model dependent and cannot directly be compared to limits from neutrino telescopes.
IceCube Preliminary
This Analysis: IC86-1, 341 Days of Livetime
Limit (bb̄)
Limit (W⁺W⁻)*
Sens (bb̄)
Sens (W⁺W⁻)*
* (τ⁺τ⁻ for m_χ<m_W = 80.4GeV/c²)
log10 (σ_SD,p / cm²)
log10 (m_χ / GeV c⁻²)
-35
-36
-37
-38
-39
-40
-41
-42
-43
1
2
3
4

Spin Independent Scattering



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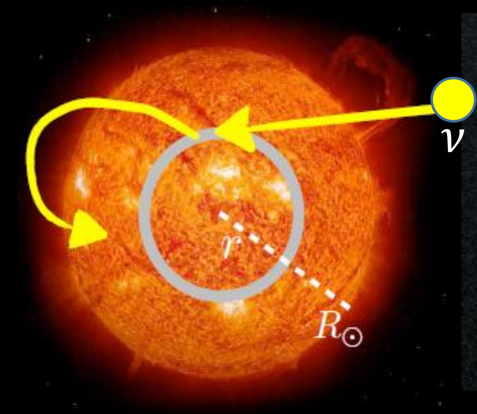

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Number density of element i -> Solar Model

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effect of solar gravity

Capture

$\Gamma_A = \frac{C_C}{2} \tanh^2(t/\tau)$

Equilibrium $\Gamma_A^{equi} = \frac{1}{2} C_c$

$\frac{dN}{dt} = C_c - C_A N^2$

Annihilation

$\tau = (C_C C_A)^{-1/2}$

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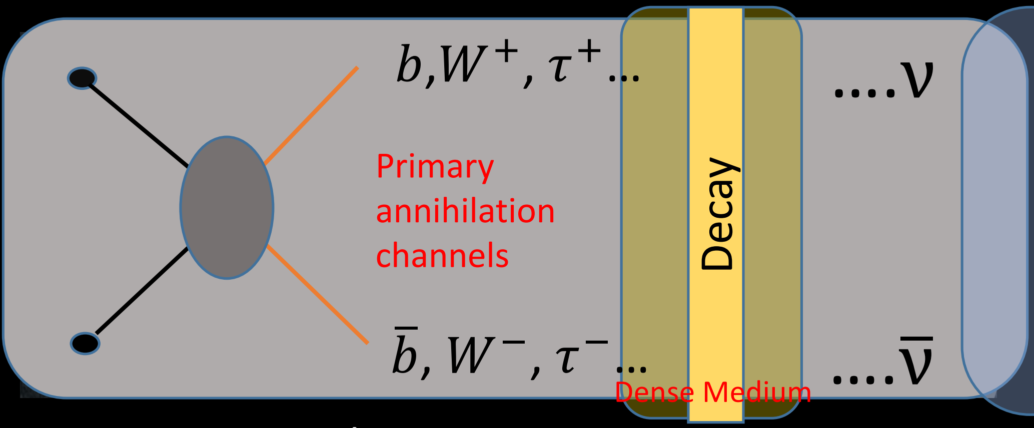

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